Monitoring Suspended Sediment Concentrations in Surface Waters of the Indus River, Pakistan from ALOS Data

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Abstract

The objective of this research work is to monitor suspended sediment concentrations in surface waters of the Indus River by means of ALOS data. The heavy sediment load brought by feeding streams in most of the rivers and reservoirs is a major problem. The emphasis of our research is to use the pattern of suspended sediment concentration (SSC) to compute the sediment load that is transferred from the upstream to the downstream. Monitoring of suspended sediment concentrations using remotely sensed data have received the most attention owing to strong relationship between suspended sediments and water surface reflectance. Reflectance of ALOS band 3 and band 4 was used to develop the algorithms for estimation of suspended sediment concentrations. Remotely sensed data makes it possible to monitor suspended sediment in river waters on seasonal bases and during floods. The research work demonstrates an example for the feasibility of ALOS data for effective and efficient monitoring of suspended sediments in water bodies.

Keywords**:** ALOS, Suspended sediments, Monitoring, Algorithm

1. INTRODUCTION

Soil erosion is a widespread problem causing the deterioration of both land & water resources. High concentrations of suspended sediment in water are a critical element in the economic feasibility of a project and could shorten the useful life of many reservoirs & dams. South Asia is one of the regions in the world where soil erosion by water and wind is a severe problem [1]. Assessment of suspended sediment volume carried by a river is vital for an adapted water resources management strategy. Satellites play a significant role in monitoring the sediment dynamics. Distribution of the suspended sediment concentration in the rivers is the key issues for analyzing the intensity of erosion in upstream watershed. Remote sensing provides a platform for monitoring seasonal sediment distribution patterns, which is not possible though traditional measurement campaign. Numerous researchers have established relationship between suspended sediment concentration and remotely sensed data. The rate of scattering and backscattering from water body is a function of size, texture characteristics of the suspended sediments and is strongly affected by other optically active water components. The main differences between the turbid and clear waters are located in the 400 – 700 nm spectral range [2], where the turbid water has significantly larger reflectance than the clear water. The objective of present research is: i) to quantify the suspended sediment in river water, ii) to develop methodology for estimation of suspended sediments by using ALOS data, iii) to investigate the feasibility and effectiveness of ALOS data for monitoring the suspended sediment distribution.

2. STUDY AREA

The Indus River, Pakistan is one of the largest sediment producing rivers in the world. Sedimentation in the three major reservoirs – Tarbela, Mangla, and Chashma in Pakistan is going to deplete their storage capacities by over 25 % by the end of the year 2010 [3]. The total length of the Indus is about 2,900 km. The Tarbela Dam is the largest earth and rockfill dam in the world; across the river Indus. The length of Tarbela dam reservoir is 97 km with an area of 260 km^2. Sediment load brought by the feeding streams is major problem in the study area. The sediment monitoring station is located 67 km upstream of the dam body. However, there is dire need to adopt methodology for effective and efficient monitoring of suspended sediments along the river.

Table 1: Land area affected by soil erosion by water and wind in South Asia

Country	Water Erosion (Mha)	Wind Erosion (Mha)	Total land Area (Mha)
India	32.8	10.8	328.8
Iran	26.4	35.4	165.3
Pakistan	7.2	10.7	79.6
Afghanistan	11.2	2.1	65.3

Source: [4]

3. METHODS

3.1. Laboratory Analysis

In an effort to quantify the relationship between Suspended sediment concentration and reflectance, water and soil samples were collected from the study area. The suspended sediment concentration data of the Indus River at the monitoring station on the day of satellite overpass was taken from Water and Power Development Authority (WAPDA), Pakistan. A hyperspectral Field SpecPro FR Spectroradiometer (Analytical Devices, Inc., Boulder, CO) was used to measure reflectance from the water surface with varying concentration (100 mg/l to 1000mg/l) of collected soil sample *(Figure 1)*. The experiment was performed in the laboratory and the depth of water column was 40 cm.

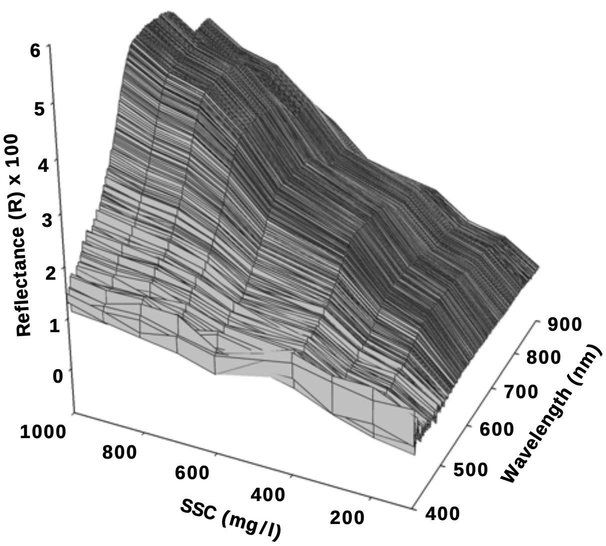

Figure1. Spectral reflectance of water with varying concentration of collected soil samples

3.2. ALOS Image

The Advanced Land Observing Satellite (ALOS) has two optical sensors called PRISM and AVNIR-2, and an L-band Synthetic Aperture Radar called PALSAR. The wavelengths covered by the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) include: Band 1 (0.42-0.50 μm), Band 2 (0.52-0.60 μm), Band 3 (0.61-0.69 μm) and Band 4 (0.76-0.89 μm). Three ALOS images acquired on 6 October, 2006 were analyzed in this research study. These images encompass the Indus River, Tarbela Dam and surrounding area in the Pakistan. The month of October is the end of the high discharge and flood period in the Indus River. For each band the image digital numbers (DN) were converted to top of atmosphere (TOA) spectral radiance (L). The TOA spectral radiance is converted into TOA reflectance for each band by using the following equation [5].

$$R(i) = \frac{\pi L(i)}{\mu_s E_s(i)} \qquad (1)$$

Where i = 1,2,3 and 4; $\mu_s = \cos(\theta)$, θ is the solar zenith angle, E_s ($Wm^{-2}\mu m$) is the solar TOA irradiance. The TOA solar irradiance for the band 1,2,3 and 4 is 1943.3, 1813.7, 1562.3 and 1076.5 $Wm^{-2}\mu m$ respectively.

The TOA measurements are then corrected for atmospheric effects. The atmospheric correction is the process of retrieving the surface radiance and surface reflectance from the satellite radiances. The dark pixel subtraction technique was used to remove or reduces the atmospheric influence on water-leaving light signals. A darkest pixel subtraction approach is simple and feasible and may apply when no ground truth data corresponding with the image is available. Hadjimitsis et al. [6] reported that, from an operational point of view, the darkest pixel approach was preferred over more sophisticated techniques that require atmospheric and meteorological data. The dark pixel subtraction is based on the assumption that an effective black body exists in the image, resulting in a pixel value of zero [7]. The minimum pixel value for that point in each band is because of atmosphere and subtracted from the corresponding band. In the upstream area of the Indus River small isolated clean water pond located in the mountains with the minimum pixel values was considered for the purpose of atmospheric correction.

4. SPECTRAL REFLECTANCE MODEL

The relationship between remote sensing reflectance R_{rs}, inherent optical properties (IOPs) of the medium, absorption coefficient a(λ) and backscattering coefficient $b_b(\lambda)$ is expressed as [8]:

$$Rrs(\lambda) = \frac{f}{Q}\frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)} \qquad (2)$$

Where f is a coefficient and the commonly adopted value of f is 0.33, which is valid for zenith sun and for large variety of natural waters [9]. In the research study area during the flood season (June-October), the suspended matters in the water are mainly composed of sediments. The presence of chlorophyll in the water is neglected. So, the absorption and scattering by chlorophyll is not taken in to account. The absorption coefficient $a(\lambda)$ and backscattering coefficient $b_b(\lambda)$ is written as follow:

$$a(\lambda) = a_w(\lambda) + a_y(\lambda) + a_s(\lambda)$$
$$b_b(\lambda) = b_{bw}(\lambda) + b_{bs}(\lambda) \quad (3)$$

Where the subscript w, y, and s represents water, colored dissolved organic mater, and total suspended sediments. The value of a_w and b_{bw} are taken from [10] for the range 400-800 nm. a_y is modeled as follow [11]: $a_y(\lambda) = a_y(\lambda_o)\exp[-S(\lambda-\lambda_o)]$, where λ_o is 400 nm, $a_y(\lambda_o)$ =0.3 m^{-1} and S=0.014 m^{-1}. Absorption by sediment is modeled as [12]: $a_s(\lambda) = kS(\lambda^{ref}/\lambda)$ where k = 0.01 & λ^{ref} = 400 nm and S is suspended sediment concentration.

Light scattered by suspended sediment is modeled using the Mie theory. $b_{bs}(\lambda)$ is written as [12]:

$$b_{bp} = \frac{3S}{2\rho} \cdot \frac{1}{\ln(D_2 / D_1)} \int_{D1}^{D2} Q_{bb} . D^{-2} dD \quad (4)$$

Where S is suspended sediment concentration, ρ is the sediment density = 2600 kg/m^3. Q_{bb} is the backscattering efficiency factor of the suspended particle of refractive index m_r. D_2 and D_1 represents maximum and minimum diameter of the suspended particles.

5. RESULT AND DISCUSSION

For the purpose of this study, the combination of ALOS/ AVNIR-2 bands 3 and 4 was selected to demonstrate the relationship between reflectance and suspended sediment concentration because SSC is strongly correlated with red and NIR domain. The developed reflectance model $(R\lambda_4+R\lambda_3)/(R\lambda_3/R\lambda_4)$ derived from laboratory experiments is the best predictor of SSC. The subscripts 4 and 3 represent band 4 and band 3 of ALOS optical sensor AVNIR-2. The term $(R\lambda_4+R\lambda_3)$ takes account of spectrum features of low and high concentrations of the suspended sediment. The term of $(R\lambda_3/R\lambda_4)$ might reduce the chlorophyll interference to the low suspended sediment concentration.

The in situ suspended sediment concentration at the monitoring station 67 km upstream of the dam was 255 mg/l (sand 20%, silt 55% and clay 15%). However the SSC at other different location was unknown. In order to deal with lack of data problem, one approach is to develop relationship between SSC and reflectance in the laboratory and apply that model on the image to quantify the SSC along the river. However the lab conditions vary significantly from the field conditions. The applicability of the laboratory developed model on the image may lead to inaccurate estimation of the suspended sediments. To quantify the SSC, the model inversion technique was adopted and the spectral reflectance curve was computed for the station with known SSC. The computed spectral curve was averaged into ALOS bands. The simulated model bands were compared with ALOS spectral signals of the same sampling station. The a_y value was assumed to be constant. The procedure consists in minimizing the difference between modeled reflectance data and ALOS reflectance data. At different locations along the river the difference between the modeled and ALOS reflectance data was minimized by varying SSC and the amount of suspended sediment was estimated as depicted in figure 2.

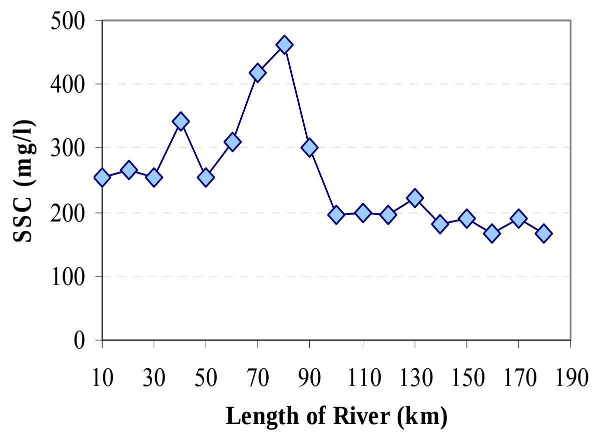

Figure 2: SSC along the river reach

It is evident from the graphical presentation that the SSC vary along the river and is higher at about 70 km upstream of the dam. The river catchment area in the range from 60km to 80km upstream of the dam is contributing heavy suspended sediment load to the river. The velocity of the river inflow containing sediments decreases upon entering Tarbela reservoir, which reduces the sediment carrying capacity of the river water. The coarse sediment tends to deposit in the upper reaches of the reservoir, while the finer particles travel downstream towards the dam and settle in the reservoir. The adopted methodology proved to be useful for quantification of SSC along the river reach.

6. CONCLUSION

The ratio of ALOS/AVNIR-2 Band 4 and Band 3 (2 Band Model) was the best predictor of SSC. The inversion technique is feasible to cope with lack of ground truth data problem. The Integration ALOS/ANVIR-2 data, in situ data, theoretical model is an effective tool for monitoring erosion, deposition areas and sediment distribution in water bodies. If ground data is available, the inversion technique may apply for atmospheric correction. The study has shown the feasibility of ALOS data to estimate the suspended sediments in the surface water of rivers and reservoirs. It is imperative to incorporate sediment assessment as an integral part of water resources and environmental planning for sustainable development and management.

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